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(5 copies)

Re: First Monthly Report on Pulsed Light Annealing #NDJ-2-30630-11 Mod 6

Dear Harin,

This letter comprises the first monthly technical status report for "CIGS Film Fabrication by Pulsed Light Annealing of Precursor Films", which is a task added as Mod 6 to ITN's subcontract #NDJ-2-30630-11, "Plasma-Assisted Coevaporation of S and Se for Wide Band Gap Chalcopyrite Photovoltaics", under the Thin Film Partnership Program. This letter describes work performed during the reporting period of September 15, 2003 through October 14, 2003.

Goals and Approach

The primary objective of this research effort is to demonstrate the production of high-efficiency thin-film CIGS solar cells on polyimide substrates by using high-rate heating from a super-intense pulsed light source. The heating rates to be investigated (millisecond time-scale) are at least two orders of magnitude higher than those reported in previous efforts to use Rapid Thermal Processing (RTP) to convert precursor materials to CIGS films for photovoltaics. Higher heating rates may be advantageous in that (1) thermal degradation of the substrate may be avoided with fast annealing and, (2) diffusion of gallium to the back of the film, which is a major limitation encountered in other CIGS RTP work, may be dramatically reduced. Goals of the present investigation are to determine the viability and challenges of using short (<50 ms) pulses from a super intense light source to:

- Convert sputter-deposited precursor films to chalcopyrite-phase CIGS.
- Improve co-evaporated CIGS electrical properties and thereby allow the use of lower deposition temperatures while retaining device performance.
- Develop a method for CIGS film production that is well suited for production scale-up and capable of producing efficiencies that match those achieved using high-temperature co-evaporation.

An additional goal will be to determine whether high-rate heating can effectively eliminate thru-film and lateral diffusion of elements during conversion of precursor structures to produce CIGS films with high front-side gallium content.

Activities

Progress during the first month of work on the Pulsed Light Annealing task can be summarized as follows:

- Identification of facilities for performing the Pulsed Light Annealing
- Preparation of sputter chamber for depositing precursor films
- Development of numerical model for predicting temperature magnitude and profiles during treatment.

These are discussed in more detail below.

Many facilities in both industry and academia exist for performing RTP, but very few of these have the ultra-high intensity light sources required for millisecond time-scale treatments. Presently available commercial RTP furnaces are designed for heating silicon wafers using banks of quartz-halogen lamps and are capable of heating rates of up to 500 °C/s. The push ultra-shallow junction CMOS technology, however, is driving several companies to develop technology for a new generation of RTP equipment with millisecond-scale heating rates. Toshiba, for instance, has reported that they are teaming with Dainippon Screen MFG Co., Ltd. and Ushio Inc. to develop a RTP tool based on xenon flash lamps that is capable of heating wafers to 900 °C in less than one millisecond. Vortek Industries Ltd. has developed a flash-assisted RTP system based on water-cooled flash lamps for silicon wafer processing. Unfortunately, there appear to be no existing facilities with Toshiba or Vortek systems that would allow us to perform applications testing. Oak Ridge National Laboratories (ORNL) has setup a facility for very rapid processing based on a plasma arc lamp that is being developed by Vortek and is capable of continuous operation at >500 kW with 20-millisecond ramp rates. We have found, however, that use of the ORNL facility would be cost prohibitive and could require giving up significant intellectual property rights. Another option we have researched would be to purchase a high-intensity flash-lamp system for our own use. We have found that purchasing a system capable of treating an area of one-square inch (large enough for fabricating solar cells) with a fluence of ~100 J/cm^2 would require roughly three times the cost-share commitment for the Pulsed Light Annealing task funding. While such a purchase is not beyond consideration for ITN (as an equipment purchase, NREL funding could not be used), it would be a significant burden. The last (and, in our opinion, best) option that we have been able to find is using the services of a German company that has developed their own flash-lamp assisted annealing system (Figure 1) designed for treating silicon wafers up to 4-inches in diameter. This system is capable of heating

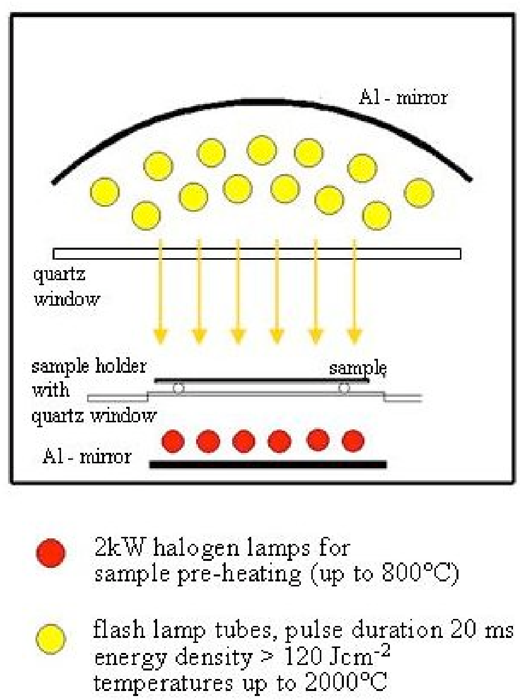

Figure 1: Flash-lamp assisted RTP system.

silicon wafers to 2000 °C and delivering fluences of up to 120 J/cm^2 with pulse durations of 3, 5, or 20 ms. Although the spectrum of light produced by the flash lamps is somewhat more blue than we had desired, the system appears more than capable of performing the rapid heating required for the present project.

In preparation for producing samples with metallic precursor layers, maintenance and reconfiguration of a sputtering system at ITN has been initiated. The selected sputtering system was previously used for sputtering of Cu, In, and Ga simultaneously with the evaporation of selenium. It was also used for long-duration annealing of precursor films in a selenium atmosphere. Although the system configuration has since been changed for subsequent experiments, returning it to its previous configuration is straightforward. One major task that is still in progress is fixing leaks due to corrosion of parts of the cathode assemblies in the high-temperature selenium environment. New parts to replace the corroded parts have been fabricated and reassembly is in progress.

A tool for estimating temperature transients and profiles in samples during pulsed-light annealing has been developed. The tool numerically solves the 1D heat diffusion equation for a system of homogeneous layers by finite differences using the Crank-Nicholson scheme and an iterative approach to handle non-linearity in the boundary conditions. The numerical algorithm has been tested with excellent agreement against several analytical solutions involving various combinations of boundary conditions and source terms. Comparing model predictions for heating of freestanding silicon wafers in argon against experimental results indicates that convective cooling has a significant effect on the wafer temperature. Efforts to better estimate the heat loss due to free convection are in progress.

Best Wishes,

Garth Jensen
Co-Principal Investigator
ITN Energy Systems

Cc: Ms. Carolyn Lopez; NREL contracts and business services